DOCUMENT RESUME

ED 205 407 SE 035 485

AUTHOR	Flegg, Janet
TITLE	Problems and Possibilities of Science Education.
INSTITUTION	Michigan State Univ., East Lansing. Inst. for Research on Teaching.
SPONS AGENCY	National Inst. of Education (ED), Washington, D.C.
REPORT NO	IRT-RS-108
PUB DATE	Jul 81
CONTRACT	400-76-0073
NOTE	27p.
AVAILABLE FROM	Inst. for Research on Teaching, College of Education, 252 Erickson Hall, Michigan State Univ., East Lansing, MI 48824 ($2.50).
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	Cognitive Processes; Curriculum Development; *Educational Improvement; *Elementary School Science; Elementary Secondary Education; Inservice Education; Knowledge Level; *Learning; Learning Problems; Professional Training; *Science Course Improvement Projects; Science Education; Science Instruction; *Science Programs; Scientific Concepts; Secondary School Science
IDENTIFIERS	*Misconceptions; Science Curriculum Improvement Study

ABSTRACT

Common misconceptions of children that may interfere with their learning science are discussed, including three aspects of science programs: complexity, fragility, and unclear learning outcomes. Special attention is given to the Science Curriculum Improvement Study (SCIS). Methods for solving problems dealing with students' misconceptions are then explored, including the improvement of program materials, the identification of the misconceptions, teacher collaboration, student writing, and the production of better teaching guides. Finally, improvements in science instruction are suggested: the teacher's focusing on conceptual change, the use of student learning to connect lessons, and the use of integrating frames. (CS)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED205407

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

JANET FLEGG

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

U S DEPARTMENT OF HEALTH EDUCATION & WELFARE NATIONAL INSTITUTE OF EDUCATION

THIS DOCUMENT HAS BEEN REPRODUCED EXACTLY AS RECEIVED FROM THE PERSON OR ORGANIZATION ORIGINATING IT. POINTS OF VIEW OR OPINIONS STATED DO NOT NECESSARILY REPRESENT OFFICIAL NATIONAL INSTITUTE OF EDUCATION POSITION OR POLICY

Institute for Research on Teaching

College of Education — Michigan State University

MSU is an Affirmative Action/Equal Opportunity Institution

SE 035 185

Research Series No. 108

PROBLEMS AND POSSIBILITIES OF SCIENCE EDUCATION

Janet Flegg

Published By

The Institute for Research on Teaching
252 Erickson Hall
Michigan State University
East Lansing, Michigan 48824

July 1981

This work is sponsored in part by the Institute for Research on Teaching, College of Education, Michigan State University. The Institute for Research on Teaching is funded primarily by the Program for Teaching and Instruction of the National Institute of Education, United States Department of Education. The opinions expressed in this publication do not necessarily reflect the position, policy, or endorsement of the National Institute of Education. (Contract No. 400-76-0073)

Institute for Research on Teaching

Teachers' thoughts and decisions are the focus of studies currently under way at Michigan State University's Institute for Research on Teaching (IRT). The IRT was founded in April 1976 with a $3.6 million grant from the National Institute of Education. That grant has since been renewed, extending IRT's work through September 1981. Funding is also received from other agencies and foundations. The Institute has major projects investigating teacher decision-making, including studies of reading diagnosis and remediation, classroom management strategies, instruction in the areas of language arts, reading, and mathematics, teacher education, teacher planning, effects of external pressures on teachers' decisions, socio-cultural factors, and teachers' perceptions of student affect. Researchers from many different disciplines cooperate in IRT research. In addition, public school teachers work at IRT as half-time collaborators in research, helping to design and plan studies, collect data, and analyze results. The Institute publishes research reports, conference proceedings, occasional papers, and a free quarterly newsletter for practitioners. For more information or to be placed on the IRT mailing list please write to : The IRT Editor, 252 Erickson, MSU, East Lansing, Michigan 48824.

Co-Directors: Judith E. Lanier and Lee S. Shulman

Associate Directors: Lawrence W. Lezotte and Andrew C. Porter

Editorial Staff:

Lawrence W. Lezotte, coordinator of Communications/Dissemination
Janet Flegg, IRT editor
Pat Nischan, assistant editor

Abstract

Considering today's technology, it would seem that everyone should have a basic working knowledge of science, yet many people do not learn much about science, especially during their early school years. In elementary school, less time is allocated to science than to any other school subject. More crucial than this lack of time is a lack of quality instruction. The teacher's guides of most packaged science curriculum materials may be poorly matched with teachers' informational needs. For example, teacher's guides seldom inform teachers about common student preconceptions and this can result in science lessons that are not meaningful. By learning to identify and deal with student preconceptions, teachers can improve their science teaching.

PROBLEMS AND POSSIBILITIES OF SCIENCE EDUCATION

Janet Flegg[1]

Students Learn Little Science

Science is getting lost in the back-to-basics movement. Amidst a growing concern that children learn the basics of education--reading, writing, and arithmetic--science has become a low-priority subject to be taught only when there is extra time. And it seems there is little time left in which to teach science, especially in elementary schools. According to Stake and Easley (Note 1), less than half of the students in the United States receive even one full year of quality science instruction during their first six years of school. Of all the major curriculum areas, science receives the least attention. Thus students have little chance to develop an interest in or a basic understanding of science during their early school years.

Yet it would seem that today's technology, the widespread use of computers, for instance, would make a general knowledge of science highly desirable if not essential. Nuclear power, pollution, genetic engineering, chemical food additives, depletion of the ozone layer, and solar energy are just a few of the topics reported in newspapers, in magazines, and on television that cannot be fully understood without a strong science education. Political leaders must make decisions about these topics without fully understanding their implications. People must vote on issues related to these topics without really knowing what their vote

---

[1]Janet Flegg is the IRT editor. She would like to acknowledge here the help and expert criticism of Charles W. Anderson and Edward L. Smith, whose research made this paper possible.

could mean. Children ask their parents questions about science, about the world they live in, and cannot get satisfying and accurate answers.

People are naturally curious about the "whys" and "hows" of the world around them, and it is certainly not for lack of interest that they do not study science. Nonscientists and nonengineers often enjoy media presentations that focus on science and technology (National Science Foundation and Department of Education, Note 2). The popularity of public television science programs like Nova and of documentaries like those reporting the work of Jacques Cousteau attests to high public interest. As evidenced by the proliferation of science magazines like Omni and Science 81, it is obvious that people do want to read about science. Science museums draw large crowds, science-fiction movies play to large audiences, and large numbers of people would rather read science fiction than anything else, yet there is a growing, nation-wide, scientific illiteracy (NSF & Dept. of Ed., Note 2).

Though interested in science, some people find it alienating. With its intricate mathematical formulas and its complex terminology, science sometimes seems beyond the scope of the average person. So although some people would like to learn about science, alienation prevents them.

Why do people feel alienated by science? Why don't people understand science? One reason might be inadequate science education, particularly for those students who do not choose science-related careers.

By the time they enter secondary school, students have already begun to specialize by tracking themselves into either college preparatory or general education courses. Those in the college preparatory track will usually be expected to take more science courses than those in the

general education track. Students who plan to pursue careers in science or science-related fields will take science courses, but most other students will avoid them because they are "too hard." Students not planning careers in science and engineering seldom study science beyond tenth-grade biology. In part, this is because many colleges have lowered their entrance requirements and few schools require advanced science classes for graduation. The result is that by the age of 16, many young people have cut themselves off from the opportunity of taking college-level science classes and the possibility of entering most science-related careers (NSF & Dept. of Ed., Note 2). More seriously though, they have denied themselves a working knowledge of science.

It's not easy to get that working knowledge. In both junior and senior high schools, the content of science courses "gives extensive and almost exclusive attention to preparation for future coursework leading to professional careers in science" (NSF & Dept. of Ed., Note 2). The focus of science courses is often theoretical rather than practical, and, therefore, not meaningful to students who will not pursue science-related careers. Because in such courses science is not made applicable to a student's daily life, students may choose not to study science. The National Science Teachers Association notes,

> much of the secondary school science curriculum is mismatched to the interests and needs of the majority of students in our schools who will not pursue scientific or technological careers. (NSF & Dept. of Ed., Note 2)

Students opting for careers not directly related to science, then, are receiving almost no science education in elementary school and choosing to take as few science courses as possible in secondary school. The decreasing priority being given to science and mathematics in secondary schools (NSF & Dept. of Ed., Note 2) may make it easy for

them to take few science courses or at least severely limit what courses they can choose from.

Students aren't the only ones who have trouble understanding science; their teachers find it difficult too. In elementary school, where children are first taught some basic scientific concepts, science is a challenging subject to teach. Many elementary-school teachers don't feel they have the science background to meet that challenge.

Elementary School Teachers Ill-Prepared to Teach Science

Teachers are themselves often dissatisfied with the science education they provide. They feel inadequately prepared to teach what they believe is an important subject. For those teachers who would rather not teach something than teach it badly, that dissatisfaction can lead to even less class time spent on science (Smith & Anderson, Note 3).

Teachers are as much a product of the educational system as are their students. They, like their students, received little science instruction in elementary school. By the time they were in secondary school, some of them had already decided that not only was science a hard subject, it was too hard for them. Therefore, they avoided science classes. When they entered college, they may not have had the required science and mathematics background to take regular science classes. Besides, the regular science classes were too detailed and theoretical for their needs. And even if they wanted to take more detailed science classes, their advisors may have advised against it. So they took science classes for teachers, classes that were often neither challenging nor interesting; in some respects, they were condescending. Certainly, those classes did not make science meaningful or relate it to everyday life.

Because few people have made a sincere effort to make science make sense to them, some teacher-education students don't find science meaningful. Perhaps no one has ever explained to them, in a clear and exciting way, the intricacies of photosynthesis. In a confusion of lenses, lights, and mirrors, perhaps the basic concepts of optics were never fully covered, and so they find optics makes no sense.

In science classes for non-science majors, the few labs provided are often rushed through with incomplete directions and faulty equipment. Students do the labs to get the correct data, the "right answer," and to finish all the steps rather than to illustrate a concept or prove a point. It is not surprising that these students approach science instruction in a similar manner when they become teachers. Because they themselves don't always find scientific concepts meaningful or logical, they cannot always teach meaningful science lessons.

Student Preconceptions Influence Learning

Children bring to school their own preconceptions, their own explanations of how the world works, and some of those explanations are wrong. It's hard to shake those misconceptions, yet that is exactly what meaningful science instruction does. In most science instruction, the teacher presents facts and theories and assumes his or her students will accept them. What is not taken into account is the fact that children already have theories that they believe. If there is room for more than one interpretation of the data, children will keep their own interpretation. If science instruction contradicts their theories, they may disregard the instruction or not understand it. Children tend to stick with their own theories, and their misconceptions may prevent them from understanding what they are taught. Their theories, if not dealt with, may render science lessons meaningless.

Light Is Not Just a Condition

Smith and Anderson (Note 4) report, for example, a common misconception children have about light that can interfere with their learning. Light travels in a straight line through space and has predictable properties. People see objects because light travels from a light source (e.g., the sun), hits an object, bounces off it, and travels to their eyes (see Figure 1).

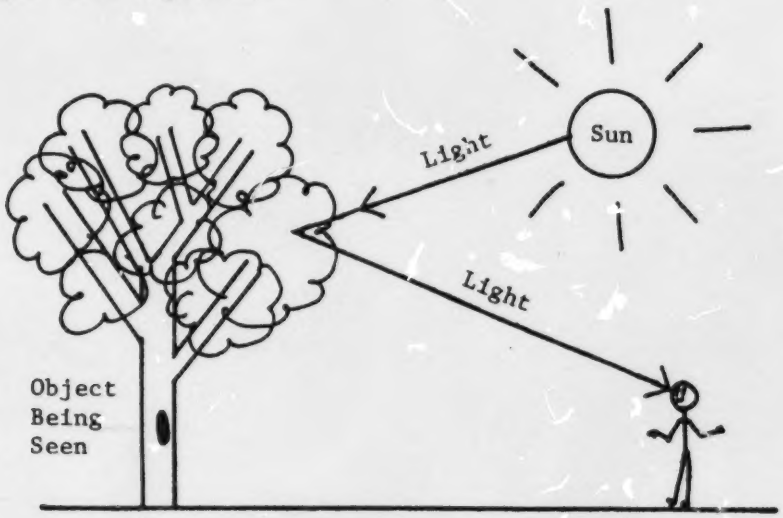

Figure 1. How light enables people to see things: Light reflects off objects and travels to people's eyes.

But most children think of light as a condition rather than as something that can travel. They think light shines on things and brightens them so they can be seen (Smith & Anderson, Note 4). They think of seeing as the direct perception of an object rather than as the perception of light bouncing off that object (see Fig. 2). Therefore, when children are taught about optics (the study of light and of how such things as lenses, prisms, and mirrors work) and asked to predict what light will do, they get confused. Because they've already decided that light is a condition, optics makes no sense to them. As David Hawkins (Note 5) says, they don't have anything in their mental files on it. It is

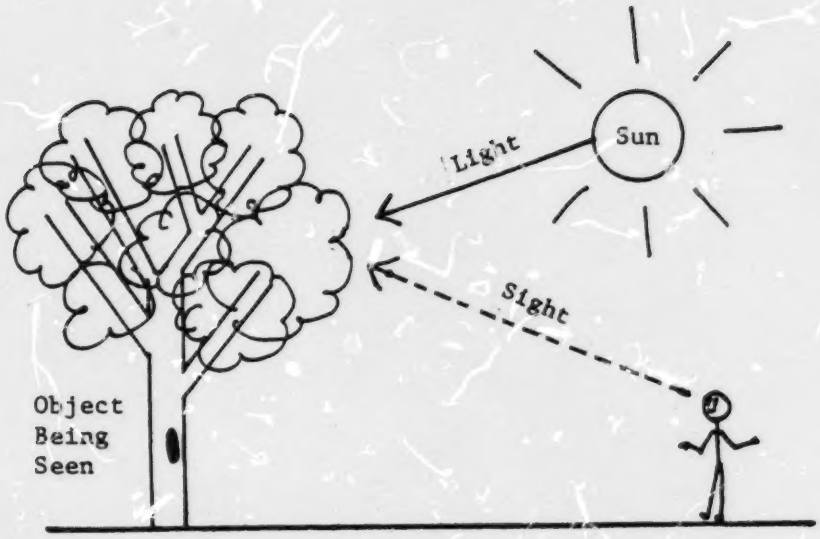

Figure 2. Common misconception about light and sight: Light brightens objects so people can see them.

nonsense to them. Effective science instruction must begin with what children already know, or they will have no context in which to understand that instruction.

Air Is Not Just Empty Space

Another misconception that many students cling to, according to Hawkins (Note 5) is the concept that air is just empty space. Hawkins reported that this misconception caused considerable confusion for some students during a lesson on how barometers and siphons work. (Barometers and siphons work on the principal that air can exert pressure on a liquid in a tube and push that liquid through the tube. A barometer is used to predict the weather by measuring air pressure. Siphons are used to move a liquid from one place to another; siphons are often used to empty the water out of above-ground pools, for instance.) Because the children didn't believe in air as a tangible substance, they could not possibly understand the explanation that air can exert pressure on a liquid and thus make that liquid move through a tube. Because they

didn't believe in the arrows shown in Figure 3, they couldn't believe the explanation. No matter how many times a teacher repeats that explanation,

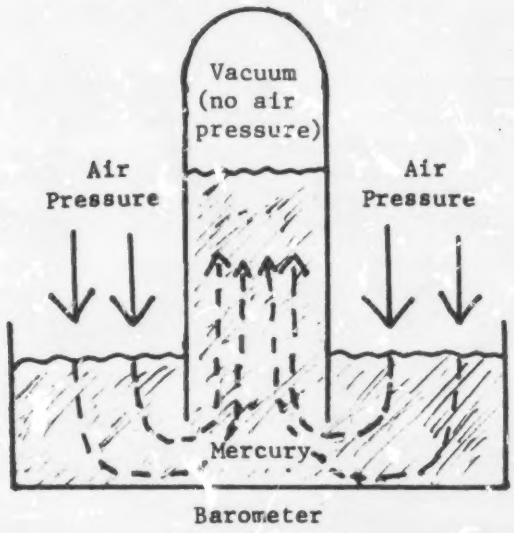

Figure 3. How air pressure makes a barometer work.

the students will not understand it because it doesn't make sense to them. The teacher feels frustrated because (s)he cannot successfully teach the lesson.

The children end up thinking themselves dumb because they can't understand barometers and siphons, although they are really quite capable of understanding them. Effective instruction would start with the students' misconceptions; it would begin by proving to the students that air is a tangible substance that does exert pressure.

Use of Textbooks and Packaged Curriculum Materials

In an effort to help teachers deal with the complexities of science instruction, including student preconceptions, science educators have written science textbocks and packaged curricula. These materials attempt to provide teachers with everything they need to teach science effectively, including backgound information about topics the teacher

might not previously studied.

In grades four through six, 90% of the teachers depend on prepared science program materials (Weiss, Note 6). In some school districts, specific packaged curriculum materials are mandated. These materials provide carefully laid out science curricula and lesson plans. The materials give instructions for doing experiments and sometimes include the necessary equipment and supplies. Logically sequenced and complete curricula in themselves, packaged materials are an extremely useful tool. Chief among the reasons for which they are helpful, even essential, is time.

If there is little time to teach science, there is even less time to plan science lessons. Yet science activities, with their eyedroppers and mirrors, their bean plants and petri dishes, require more careful planning than most other lessons. Teachers don't have time to do the kind of planning they know is needed, so they rely on packaged curriculum materials to do much of that planning for them.

The activity-based programs so widely advocated by science educators keep students busy. To keep track of those busy students and keep them on-task, the teacher must be even busier. (S)he must see that enough materials are available, distribute them, tell students what to do, answer questions, monitor use of the materials, make sure that students complete assignments, and give directions for and monitor clean-up. Under such circumstances, reliance on packaged materials becomes a necessity. Any examination of elementary-school science education must therefore begin with an examination of packaged curriculum materials and how they are used.

How Are Program Materials Used?

Program materials bring structure and order to a complex subject, and teachers and/or administrators, sometimes with the help of parents, may choose from a number of good programs the one they feel is most appropriate. A popular program is the Science Curriculum Improvement Study (SCIS), an activity-based program including a kit with materials for a sequence of "hands-on" activities, a teachers' guide, and student manuals in which hypotheses, observations, and conclusions are recorded. With SCIS as one of their objects of study, two researchers working jointly with the Institute for Research on Teaching and the Science and Mathematics Teaching Center at Michigan State University, Edward Smith and Charles Anderson, have spent a great deal of time observing science instruction in elementary schools. Their reports of competent teachers using SCIS detail how program materials are actually used in classrooms.

One Classroom as an Example

Sendelbach and Smith (Note 7) observed a sixth-grade classroom in which 32 students were taught a five-week SCIS unit on the oxygen-carbon dioxide cycle (for a complete report of this case study, see Smith & Anderson, Note 3; Sendelbach & Smith, Note 7). The unit was designed to teach students about the exchange of gases between plants and animals (see Fig. 4). Plants take in carbon dioxide and give off oxygen in the light. In the dark, they take in oxygen and give off carbon dioxide. Animals always take in oxygen and give off carbon dioxide.

The children did a series of experiments designed to illustrate this concept.

The first experiment was preparation for the second; when the children blew through a tube that had been placed in a container of

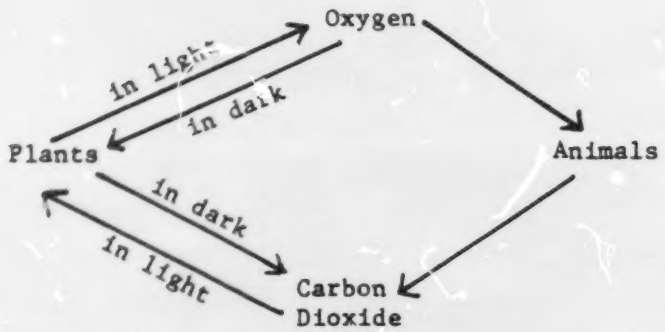

Figure 4. Gas exchange in plants and animals (the oxygen-carbon dioxide cycle). (This diagram was printed in the teacher's guide.)

bromthymol blue (BTB) and water, bubbling their breath through the liquid, they saw that the liquid changed color. The teacher explained that BTB changes color when it reacts with carbon dioxide. (BTB is a chemical indicator. A chemical indicator is a chemical that changes color when it reacts with a specific substance; it indicates the presence of that substance by changing color. BTB indicates the presence of carbon dioxide when it changes color.)

To test that idea, the teacher had her students do an experiment designed by SCIS to show that it was indeed carbon dioxide that caused the color change and not some other gas, like oxygen.

Using the experimental set-up shown in Figure 5, the teacher

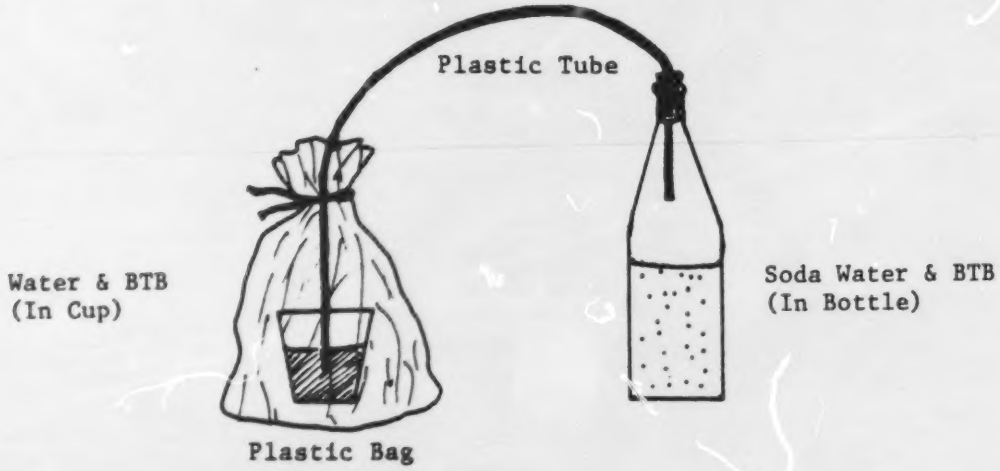

Figure 5. Set-up for soda-water experiment.

put BTB in the cup. (Because she found the directions in the teacher's guide unclear, she was not aware that the soda water should also have had BTB added to it.)

The students observed that the BTB and water solution in the cup changed color. This was because carbon dioxide (the bubbles in the soda water) escaped from the soda water, passed through the tube, and bubbled up through the liquid in the cup. It had to be carbon dioxide that caused the color change because no other gas could enter the system, but not all of the students were convinced. Some of them still held the misconception that oxygen is needed to change BTB back to blue after it has reacted with carbon dioxide. But to actually change BTB back to blue, the carbon dioxide must be removed (see Fig. 6).

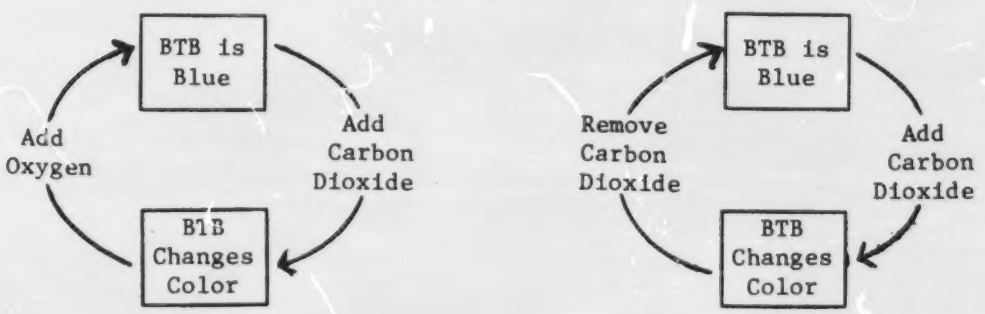

Figure 6. Student misconception versus reality of BTB color changes.

The final experiment done by the children illustrated the effects of light on the gases plants and animals use and produce. In separate vials containing water and BTB, the children put snails and Anacharis (a small green plant that grows in water). They put some of the vials in the light and some in the dark (see Fig. 7).

(All four test tubes contain water and BTB.)

Figure 7. Experiment showing effects of light on gas production.

BTB changed color in the test tubes with snails in them and in the test tube of Anacharis kept in the dark. It stayed blue in the test tube of Anacharis kept in the light.

From this experiment, the students saw that animals give off carbon dioxide in light or dark and that green plants give off oxygen in light and carbon dioxide in the dark. (The fact that plants are always respiring and thus producing some carbon dioxide at all times, even in the light, was not covered in this unit.)

Did the Students Understand the Material?

Multiple choice tests given to the students after the unit showed that most of them didn't understand the material. Report Smith and Anderson (Note 3):

> Four students gave evidence of believing that animals always give off oxygen, seven students gave evidence of believing that plants always give off oxygen, three of those students gave evidence of believing both propositions, four students gave evidence of believing that oxygen changes the color of bromthymol blue, and two students gave evidence of believing all three propositions. ...Only three students gave evidence of holding the correct conception of gas exchange in plants. Only three students gave evidence of holding the correct conception of the effects of oxygen and carbon dioxide on bromthymol blue. *No* student held correct conceptions of both.

A good teacher using a good program was not able to impart to her students an understanding of the oxygen-carbon dioxide cycle. What went wrong?

First, because of problems with the teacher's planning procedure and unclear presentations in the teacher's guide, report Smith and Anderson (Note 3), she didn't understand the logic behind two of the activities.

She didn't realize that the soda-water experiment was intended not only to show that the BTB and water solution changed color when carbon dioxide was bubbled through it, but to show that the soda water and BTB solution changed color when carbon dioxide escaped from it. The key point was that the soda water and BTB solution changed color because carbon dioxide left it, not because oxygen entered it. Because the teacher missed this point, she did not put BTB in the soda water; the experiment was incomplete. On one occasion she stated that oxygen turns yellow BTB back to blue, which is false.

Also, she didn't understand that green plants can only produce oxygen in the light. Therefore, in the experiment using Anacharis and snails, she expected no difference in color between vials in the dark and vials in the light. Poor printing of the diagram in Figure 4 contributed to this misunderstanding. The arrow showing that plants use oxygen in the dark was unclear, and the teacher thought it was a printing error.

The subtle modifications the teacher made in experimental procedure deemphasized or altered the program's meaning. Thus the students did not learn the material well.

Program Material Difficulties

According to Anderson and Smith (Note 8), there are three aspects of the SCIS program, which are also common to other programs, that may create teaching difficulties: complexity, fragility, and unclear learning outcomes.

Complexity. Elementary school classrooms in which science lessons are going on are complex settings in and of themselves. If 30 students are doing an experiment, there's a lot happening and a lot that the teacher must keep track of. According to the SCIS time line, at any one time during the school year, there may be several program activities in progress at once. The students might be growing bean plants for one experiment while finishing up graphs for another. And the classroom routines a teacher needs to set up to sustain SCIS activities are complicated. The soda-water experiment was indeed complex, so complex that the teacher had trouble understanding the directions.

Fragility. SCIS cannot withstand much abuse or static. If something goes wrong, it breaks down. At times, it presents an information overload to teachers and students, more information at once than they can handle. And there is so much going on during the program activities that classroom management problems arise. If a shipment of living organisms (e.g., plants, snails) is late or if the organisms die, the class gets behind on everything, and the teacher may have to omit something later on, sometimes something that is crucial to the concept being taught. Seemingly minor deviations from the program materials can have major consequences for student learning.

Because the teacher did not put BTB in the soda water, her students were not able to observe the color change that should have resulted from

the carbon dioxide leaving the soda water (the BTB should have gradually returned to its blue color as the amount of carbon dioxide in the soda water decreased). As a result of this, some students were not convinced that carbon dioxide made the BTB change color, they still thought oxygen did it.

Unclear learning outcomes. It is not always clear from the SCIS materials what each activity's projected learning outcomes are. Isolated statements tucked away in the "Background Information" section of the teacher's guide are not enough to make learning outcomes and relationships between activities clear, especially considering the fact that many busy teachers don't read the "Background Information" sections.

The only stated objective for the oxygen-carbon dioxide cycle unit was a vague one: Students were supposed to learn about the exchange of gases between plants and animals. The smaller, more specific goals were not clearly stated in the teacher's guide, goals like having the students realize that BTB changes color when it reacts with carbon dioxide. Without achieving this and other supporting goals, students could not fully understand the unit.

Possible Program Material Improvements

Smith and Anderson suspect the main problem with packaged curriculum materials to be a "failure of communication" between the teacher's guide and the teacher. The teacher's guide is poorly coordinated with real-life classroom planning. It doesn't allow for management problems or late supply shipments. Learning outcomes are not clearly and explicitly stated, and the contributions of each activity toward achieving these outcomes are seldom made explicit. The two researchers believe that alterations in both the teacher's guide and in actual planning procedures could make science instruction more

meaningful.

Smith and Anderson have begun informally developing alternate versions of teachers' guides. Some possibilities they consider promising are the construction of chapter overviews that include information about student preconceptions and desired learning, presentation of long sequences of activities as groups of shorter sequences, and the use of a three-column format in which information about procedures, likely results, and student learning is juxtaposed.

Information about student preconceptions is especially important. Student preconceptions are a pivotal factor in science education; recognizing and dealing with student preconceptions may be the key to effective science instruction.

What can a Teacher Do?

Identify Student Misconceptions

Teachers need to understand their students' misconceptions and correct them, or the students will never really understand the material. While teacher's guides can give help with this, they cannot provide all the answers. Each teacher must deal with his/her students, who may have their own unique misconceptions. First a teacher must identify student misconceptions.

Teacher collaboration. Hawkins (Note 5) said that teacher collaboration is an effective strategy for finding out what students' misconceptions are. An intervening, active participant (the teacher) and a relatively passive observer (a researcher or a fellow teacher) can do it. The observer watches students closely and tries to determine what their misconceptions are. On the basis of observations by the participant and the observer, the participant can then try teaching differently.

The observer watches the effects of any change and discusses them with the teacher.

Student writing. Another way teachers can identify student misconceptions is through student writing. Most student writing during science lessons is merely used for accountability. By writing a series of definitions, students prove they have read the assigned chapter (or at least the definitions). By writing numbers in the blanks and answering a few questions, students prove they have done the assigned experiment. But writing can also be used as a means of communication between student and teacher.

A teacher can learn a great deal about student misconceptions by asking students to explain, in writing, a scientific concept or natural phenomenon. Every child must contribute; no one can be overlooked. And unlike fast-paced discussions, writing can be reflected on and thought about by the teacher. Writing can thus serve as a record of student misconceptions. Once a teacher knows what those misconceptions are (s)he can try to correct them.

Writing can also stimulate student thinking. Asking students to explain what they have learned in writing forces them to think about what they have learned. To explain to the teacher in writing what they have learned, they must first think about the material and explain it to themselves. Such writing can also serve as a check whereby the teacher can see if the students really have learned the material.

Smith and Anderson will, in 1981, begin a study of writing in science to examine how writing may be used in science instruction and the effects on instruction that writing may have (Smith & Anderson, Note 9). Said the two researchers, "We are especially interested in the potential use of writing tasks to enhance students' conceptual learning in science."

Better teacher's guides. Writing in science and teacher collaboration can be helpful, but both assume that the teacher understands the scientific concepts (s)he is teaching. However, teachers, like all adults, may have the same misconceptions their students do. If science curriculum materials are well-written, teachers may be able to correct their own misconceptions as they use the materials.

Smith and Anderson (Note 3; Note 4) suggest that clearer, more informative teachers' guides could help teachers correct their misconceptions, but such guides will take considerable time to research, write, and produce. In the meantime, Smith and Anderson (Note 4) suggest three things teachers can do to improve their science instruction based on the strategies of successful science teachers they have observed.

Focus on Conceptual Change

The first of these is to focus on conceptual change. By paying close attention to what students' preconceptions are and contrasting those with the conceptions being taught, teachers can improve both their students' and their own understanding of why certain experiments are done or certain chapters are read. This may also help teachers to better understand their own conceptual difficulties. A teacher might, for instance, stress those concepts students may have incorrect preconceptions about by contrasting what the experiments show with what people might think would happen. Asking students to predict what will happen in an experiment is an excellent way of finding out what student preconceptions are.

Take, for example, the soda water and BTB experiment discussed earlier. In this experiment, BTB gets bluer when carbon dioxide escapes,

in the form of bubbles, from the BTB and soda water solution. This is clear evidence against the misconception held by many students that oxygen changes BTB back to blue. But students may not see this as clear evidence against their preconception unless they first commit themselves to that preconception. And the teacher cannot stress the experimental results as evidence against a student preconception unless (s)he knows that some of his/her students have that preconception.

Use Student Learning to Connect Lessons

Smith and Anderson also suggest that teachers use student learning rather than procedures to connect lessons. Rather than regarding lessons as a sequence of activities to be done or pages to be read, teachers might construct a "story line" based on student learning. Each activity or reading assignment adds an idea or fact to a developing conceptual framework. Stressing the development of that conceptual framework instead of the procedures by which it is developed may make science instruction more meaningful.

In the series of experiments presented earlier in this paper, for example, the story line focusses on carbon dioxide. BTB indicates its presence, plants and animals produce it in the dark, animals produce it in the light, and plants use it in the light. If a teacher has a firm grasp of the story line, (s)he can make informed judgments on lesson details and procedures.

Use Integrating Frames

The two researchers' third suggestion is closely linked to their second. In order to construct a "story line," each lesson must have what Smith and Anderson call an "integrating frame." Procedures,

results, and learning ought to make up an integrated whole. Making this difficult is the fact that teachers' guides may separate statements about procedures, results, and learning, even though they pertain to the same experiment or activity. Thus, teachers must work hard to see how everything fits together and to convey that integrated whole to their students. By stressing those parts of each lesson that link them to other lessons, the integrating frames, a teacher can integrate instruction. The question, "What does the BTB and soda water experiment tell us about carbon dioxide?" helps students to connect that experiment logically with other experiments they've done concerning carbon dioxide.

Effective science instruction is difficult, but it is not impossible. And it is worth striving for. Most children enjoy science, and they are anxious to learn about it. They need good science education because science increasingly touches their lives. If they have at least a basic understanding of science, they will have no need to feel afraid of or threatened by it.

Reference Notes

1. Stake, R.E., & Easley, J. Case studies in science education. (Two volumes, GPO, NFG SE 78-74.) Washington, D.C.: U.S. Government Printing Office, 1978.

2. National Science Foundation & Department of Education. Science & engineering for the 1980's and beyond. Washington, D.C.: U.S. Government Printing Office, 1980.

3. Smith, E.L., & Anderson, D.W. Planning and teaching of intermediate science. A proposal submitted to the Science Education Development and Research Division of the National Science Foundation, Washington, D.C., 1980.

4. Smith, E.L., & Anderson, C.W. Planning and teaching intermediate science: Progress report (submitted to the National Science Foundation). Michigan State University, 1981.

5. Hawkins, D. Virtues and limitations of naturalistic research in classroom settings. Colloquium presented at the Institute for Research on Teaching, Michigan State University, June, 1980.

6. Weiss, I.R. Report of the 1977 national survey of science, mathematics, and social studies education. Research Triangle Park, North Carolina: Center for Educational Research and Evaluation, 1978.

7. Sendelbach, N.B., & Smith, E.L. A case study of activity-based science teaching and its antecedents. Paper presented at the annual meeting of the American Educational Research Association, Boston, 1980. (More detailed report available as Technical Report 80-7. East Lansing, Michigan: Science and Mathematics Teaching Center, Michigan State University, 1980.)

8. Smith, E.L., & Anderson, C.W. Planning and teaching intermediate science: The problem of meaningfulness. Colloquium presented at the Institute for Research on Teaching, Michigan State University, May, 1981.

9. Smith, E.L., & Anderson, C.W. Writing in science. In The IRT technical proposal, a proposal submitted to the National Institute of Education in response to RFP NIE-R-81-0003. East Lansing, Michigan: Institute for Research on Teaching, Michigan State University, 1981.